View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by University of Southern Queensland ePrints

Engaging Minds through Problem Solving - a day in the life of a scientist

Lucy George and Kevin McDougall
University of Southern Queensland, Toowoomba, Queensland 4350
E-mail: georgel@usq.edu,au
Tel: +61-07-4631 2692 Fax: +61-07-4631

Abstract

Engaging the minds of students during science lessons is a challenge for science teachers. "Why do we have to learn this?" has been a common question posed by the majority of secondary science students in our classes for decades. The problem solving approach in secondary science teaching will become the norm in the future of science teaching and learning. It will eradicate any notion of irrelevance of learning science faced by many secondary students in our schools today. Science learning through problem solving will not only achieve intended educational outcomes but also increase students' desire to participate in learning science and develop an attitude towards life-long learning. This paper discusses the pros and cons of trying to engage the minds of 14 year-old girls at a Girls Maths and Science Summer School through solving a crisis by being a scientist for a day.

Introduction

The University of Southern Queensland holds a Girls Maths and Science Summer School each January. The program is mainly funded by Education Queensland and is organised and run by volunteer staff from mainly within the university. One of its aims is to influence girls entering Year 10, to consider enrolling in science and mathematics when they go on to Year 11, by exposing them to a variety of fun activities in Maths and Science during the summer school. Traditionally, the school comprised of workshops aimed at giving the girls a taste of a myriad of science activities. In 2001, the summer school adopted an interdisciplinary holistic problem-based solving approach to help students see the link between science, maths and technology and its relevance in the real world (Stretton, 1985).

In this paper we describe a one-day program aimed at engaging the minds of 14 year-old girls at a Girls Maths and Science Summer School through solving a real-life crisis, by being a scientist for a day in the framework of problem-based learning (PBL). We will describe the developmental process of the program and the students' responses to such an approach. It will also give teachers an insight to the concept and practicalities of problem-based learning (PBL), which is widely used in many universities around the world.

Although an inter-disciplinary curriculum was developed, according to the rationale and the intended educational outcomes, our focus in this paper will be on the use of GIS technology in problem solving. As GIS technology is fairly new to most teachers, we will present findings from the students' responses to the problem-based solving approach using this technology and comparing it to other discipline-based approaches such as chemical qualitative and quantitative analyses. We will also discuss the pros and cons of the problem-based learning approach used in this one-day program and how it can be applied to the normal day-to-day science teaching and learning in the secondary science classroom.

Definition of Problem Solving

A School Perspective

In most schools, problem solving commonly refers to the application of higher-level thinking skills such as analyses and the application of prior knowledge and conceptual understanding, plus usually rote-learned algorithms to solve mainly quantitative problems. A linear problem-solving model such as this tends to limit students' creative thinking in real-life problem solving by locking them into a set pattern of thinking inside a box. Once conditioned, a student may not be able to apply previously gained knowledge in maths or science when confronted with unfamiliar problems, which often results in anxiety and a sense of failure (Ronning, McCurdy, and Ballinger 1987, p.509). Such is the school experience of most of our science and maths students.

Discipline-based problem solving in schools

Problem solving in schools is currently compartmentalised. In biology, Stewart (1988), discusses two main types of thinking involved in solving genetics problems. The first is reasoning from causes-to-effects (e.g. what are the effects of genetic mutation?). The other is reasoning from effects-to-causes (e.g. the effects of X can be traced to the cause Y, which involves a multivariate analysis). Cause-to-effect problems that require content-specific algorithms are the most commonly used since most of these problems are easily available in textbooks, but Stewart (1998) argues that such problems do not help students to acquire insights into the nature of science. Effect-to-cause problems are more difficult to design and require access to computer-generated information. Stewart argues that the most important insight that students can gain from solving effect-to-cause problems is an understanding of science as an intellectual activity (1988, pp. 243-251).

Problem solving in chemistry, appears to focus on quantitative problems (Bodner, 1987), which tend to hamper maths anxious students who might otherwise enjoy chemistry, which is about understanding the nature of matter. The same applies to physics (Watts, 1988, pp. 74-79) and maths, with students often left wondering if only they could master the technique of when to use what formula (a common complaint of students)?

Current trends in problem-solving

According to Good and Smith (1987, pp. 31-36), in the 1960's problem solving in science education referred to how puzzles and games were solved. Current research into problem solving involves information processing theory, which proposes that two processes are needed in problem solving – that of retrieving and utilising pertinent information to solve problems. The fact that we live in a knowledge society demands that information processing skills including the access and management of new knowledge, become part of the mindset of today's technological learning society.

The PBL model involves the use of real problems for creating active, student-centred learning environment and has been implemented at many universities within Australia at Griffith, Newcastle and Hawkesbury since the 70's (and around the world). Many more universities are doing the same today in more and more courses.

Any PBL innovative program design can be divided into problem formulation, data collection, brainstorming solutions, evaluating, selecting and implementing solutions. This learning model can be used for teaching most content and skills and the development of attitudes, and is applicable to all student-learning levels with the use of suitable strategies. However, it requires a cognitive and affective change in the teacher's role as a guide to learning.

Computers in schools will have to become an everyday tool and used as experts use them today – not just as an encyclopaedia for school projects, or as a word processor. In today's knowledge society, the accessing, and retrieving of useful knowledge and its application is most efficiently carried out by using computer technology. It is with this in mind that we have developed and designed our problem to incorporate the use of GIS technology.

Origins of Problem-Based Learning

Problem-Based Learning (PBL) has its origins in medical education – more specifically in the clinical aspects of medical education where the need arose to put the theory into context. McMaster University in Canada was one of the first to use PBL systematically as part of their teaching programs in the early 1970's (Struijker, Boudier and Smits, 2002). PBL is characterised by carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies and team participation skills (Education Development Unit of London Guildhall University). In a PBL setting, learning is student-centred and the teacher tends to act as a facilitator and resource guide rather than solely as a provider of knowledge and information.

In PBL a problem situation is presented before any knowledge is given and uses the problem for the purposes of learning new knowledge. The students must first identify the type(s) of knowledge to be acquired (comprehension, analysis of problem), how to acquire it (process planning, implementation for knowledge and data collection) and then apply it to solve the problem (analysis, synthesis and evaluation).

Donald Woods (1985), distinguishes between problem solving and exercise solving by defining problem solving as "the process whereby the 'best' value is determined for some objective or unknown, subject to a specific set of constraints and criteria. Problems are those situations where there is no immediately apparent solution or direction of attack." Woods (1985) lists the following skills needed to be efficient and effective in problem solving:
- an organised approach or "strategy"
- skills to think creatively, broadly, to analyse, generalize, simplify
- skill with adjusting and controlling our attitudes (e.g. stress, anxiety, motivation, decisiveness)
- ability to apply a wide variety of hints or heuristics
- skill at evaluation
- a range of pre-requisite skills (e.g. communication skills, group skills, learning skills).

The Objectives of the PBL approach for the GMS Summer School

1. To present a holistic view to problem solving involving science, maths and technology.
2. To challenge and extend students' creative thinking abilities by solving a critical problem.
3. To introduce students to the capabilities of GIS as a powerful problem solving technological tool.
4. To help students develop an awareness of the importance of cooperative and experiential learning when faced with solving unfamiliar problems.

5. To encourage an attitude of confidence or a spirit of ‘can do’ in whatever problem situation by learning to be resourceful.

The Design and Developmental Process

1. Problem Design-choosing a real-life problem suitable for our objectives.
2. Type of critical knowledge involved – know from the design, the type of knowledge students will need to acquire before they can effectively solve the problem.
3. Involve other experts to supply critical knowledge and to act as facilitators.
4. Skills for the problem solving process – assume that students have different needs.
5. Design of structured worksheets to guide first-time problem solvers to acquire critical knowledge step by step - ensure that instructions are clear and facilitators are on hand.
6. Facilitators as resource guides and to encourage students to think laterally.

Problem design

An inter-disciplinary problem-solving approach required an inter-disciplinary team effort. While the idea was conceived in my mind, the expertise of my colleagues were vital to help make the problem as realistic as possible and do-able for would be Year 10 students. Our team comprised of a chemistry, biology, two GIS lecturers and a former science teacher. The problem solving was to be an intellectual as well as a hands-on activity, with technology playing a large part in the final analyses, synthesis and decision-making.

A Real or Imaginary Problem?

Setting The Scene

The phrase ‘it only happens in movies’ is obsolete in today’s world. Terrorist activities are no longer confined to the world’s hot spots. There was a huge water contamination scare in Sydney before the Sydney Olympics in 2000 and I had often wondered what would happen if such an event did take place and a city’s water supply was held hostage to terrorists’ demands. My problem was set against such a scene.

To make it fun and light-hearted, the problem was introduced with novelty. Three drama students enter the room in a sombre mood, unannounced. One of them read the news through a cut out box. The ‘Mayor of Toowoomba’ was being interviewed by a reporter and confirmed that what they heard on the ‘news’ was true – that terrorists had captured all the scientists and were holding the city at ransom. If their demands were not met in 24 hours, the city’s water supply would be totally poisoned. There were already some fatalities. The ‘Mayor’ had come to commission the ‘Alpha Team’ (the girls) to solve the crisis. The ‘Alpha Team’ was a team of junior scientists who had access to ‘deceased scientists’ brains’ on computer. (Every city has its own Alpha Team, trained to take over in such an event; a government initiative due to rising terrorist activity in the world.)

Initial Student Response

Some students were stunned, some didn’t know how to react, and a few chuckled quietly and some smiled in disbelief and asked ‘is this for real?’. From then on, the students were guided to begin the problem solving process with a brainstorming session. As they had only less than 24 hours, they were encouraged to be active thinkers. Their first job was to decide who gets first priority to the limited supply of air-flown water from Brisbane. Their task was then:

- to identify the contaminant – biological/chemical toxin.
- To measure the level of the contaminant in ppm/counts and to assess the possibility of decontamination to save the ecosystem/foodchain.
- To locate and isolate the point of contamination using GIS technology.
- To locate a new safe water source and to begin construction of a dam/bore using GIS.

Key information and clues

A starting point

To assist the students, several clues and vital information were given. It was made clear that there were reported fatalities of a couple of sheep and one person at different locations. Students were also made aware that different levels of contaminant were needed to kill animals and human beings.

The students had to determine if these deaths were in anyway linked to the terrorists' poison or if they were simply unrelated incidents, perhaps due to an algae bloom or foul play. They had to check the locations and relate them to possible contamination sites and obtain autopsy reports. They had to analyse the water samples from the death scenes. There were three main activities, two lab analyses and one GIS activity. At the end of the day, each group would present their findings and solutions as well as to justify the decisions they made based on their findings. This was aimed at getting them to evaluate what they had done, and to communicate them to their peers, who may then assess their report or ask questions to seek clarification.

What are Geographic Information Systems (GIS)?

Geographic information systems (GIS) are a relatively new technology that has developed over the past 30 years to manage the increasing range of digital mapping and geographic information. In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system (United States Geological Survey, 2002).

Geographic information systems technology can be used for scientific investigations, resource management, and development planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, or a GIS might be used to find wetlands that need protection from pollution. It is estimated that approximately 80% of all decisions have some geographic or spatial component e.g. where will this new business need to be located, what is the demographics of my customers within my sales area, how do we track the source of the pollution.

Over the past 20 or more years paper maps have been converted into digital formats to allow more efficient update and generation. In addition other new technologies such as the Global Positioning System (GPS) and satellite imagery has allowed geographers, surveyors and scientists to capture information on our built and natural environments accurately and quickly. All of this data can now be combined and analysed in a GIS to support better decision in an increasing range of areas. In particular, GIS has now become an essential operational and research tool for scientists in areas such as environmental management, climatology, ecology, demography, marine science and engineering.

Geographic information systems support real life decision-making through the analysis of layers of digital mapping information (see Figure 1). Attached to these layers of data are other associated textual information such as the owner of a land parcel, the name of a road or the soil type and its characteristics. This attribute information provides a further level of detail for the refinement of any query or analysis of the database.

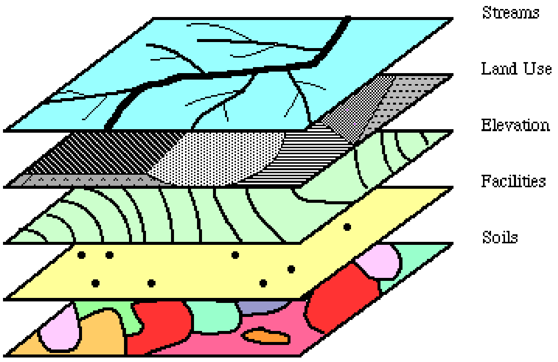


Figure 1: Concepts of layers of GIS information

In its simplest form, GIS analysis may encompass the combination of two or more layers of information to identify some spatial correlation. For example, if we wanted to identify all those properties that are affected by a one in 50 year flood, we can simply overlay the flood line with the land property layer.

GIS in Schools

Schools have been using, and realising the benefits of, Geographic Information Systems (GIS), particularly in the 'old' Geography subject area, on an ad hoc basis. Time, budget constraints and lack of readily available datasets have, however, limited its use in most schools. New syllabuses developed by the Queensland Schools Curriculum Council and Board of Secondary School Studies for Studies of Society and the Environment (SOSE) and Geography allow greater flexibility in the area of technological innovation, including GIS.

The availability of GIS in schools will promote the trans-disciplinary, multiple competency approach of this program and will support the development of curriculum linked to real life applications. It is expected that GIS capability will significantly expand opportunities to enhance the scope and content of teaching as teachers and students begin to harness the potential of this technology and data. Already in Queensland over 50 schools around the state have began to integrate GIS as part of their tools for teaching. GIS software developer, ESRI Australia, have now provided starter packs that enable schools to get up and running using GIS software and data at a discounted price (see http://www.esriau.com.au/prodserv/educ/k-12/gisschools.asp).

As GIS technology matures in its user-friendliness, and the access and affordability of data improves, the applications for GIS, including their use in school curriculum, will continue to expand. Already it is widely used around the world at all levels of teaching. Numerous examples and resources can be identified including: http://www.sln.org.uk/geography/gis.htm (United Kingdom), http://egis.eagle.co.nz/schools/index.htm (New Zealand), http://kangis.org/ (K12 GIS in USA) and http://www.standard.net.au/~garyradley/gis/GISMenu.htm (Australia).

Overview of the Problem

In the limited time available students were presented with a potential real-life problem that may face a community. In the scenario the drainage/stream system southwest of Toowoomba, Queensland appears to have been deliberately contaminated. The drainage system forms the main water supply for the city of Toowoomba. Laboratory analysis has confirmed that the water supply is contaminated, but the source of this contamination has yet to be identified. The contamination has already caused a number of fatalities and is causing irreparable damage to the water quality, wildlife (fish and other aquatic organisms), and the drinking water supply.

When the exercise was first run in January 2001, some may have considered that the exercise was not a true reflection of a possible real-life situation and thought that such scenario would never occur. However, the events of September 11 have brought into sharp realisation that such events are not beyond those people that want to inflict terror on a community. During and after this tragedy in New York, GIS was an integral tool for the emergency management and subsequent clean up plans at the around the World Trade Centre.

During the problem solving, students played the role of the investigating scientists that were assigned to investigate, track down, and identify the most likely source of the pollution and possible perpetrators. They were provided with information, computer resources and clues to assist in their investigations. The students were asked to use the geographic information system (GIS) to determine:

- The most likely origin of the contaminant given the clues below. In forming your decision you will also need to consider the ability for the terrorists to access the site by air (helicopter) or road.

- A plan to clear the contaminant or to stop it from entering the main drinking supply. You may also be required to estimate how long it will take for the water supply to be clear.

- You will be required to justify your decisions and give reasons.

Students were provided with clues to assist them in their work. Some of these clues included:

- From the initial reports and analyses, the following are some clues about the source of the pollution have been gathered

- The pollution appears to have originated in a creek located in land identified as *pasture* or *forest* areas.

- Because of flow and surface water characteristics, the contaminant is most likely to have been dispersed or released in *very steep slopes* (e.g. >30% slope) to enable it to flow overland.

- The contaminant is also most likely to have released within the waterway or from a property *at least 300 meters from the creek* in order for the contaminant to be effective.

- The owner of the property where the contaminant has been released should be considered to be a suspect. Given the level of contamination, the terrorists may have also required access to the site by either road or air.

Digital data was also available to the students including digital maps of the creek system, land use, slope, property ownership, and satellite image of the vegetation. All of this data was provided over a 10 km x 10 km area. The students were given access to the GIS software – ArcView 3.1 which is a popular GIS analysis package.

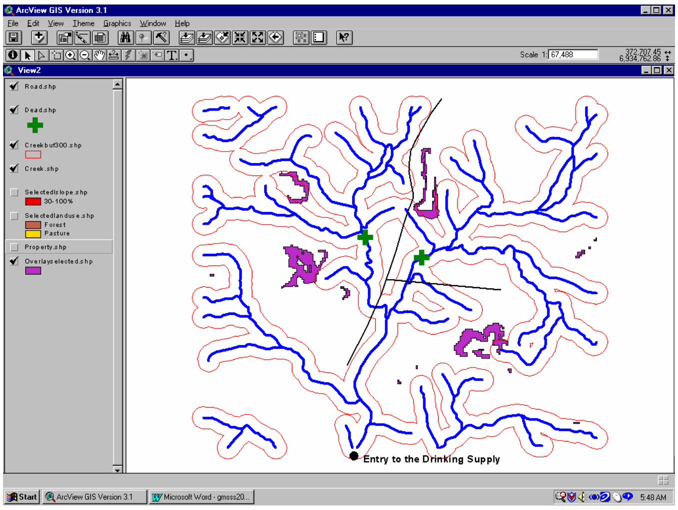


Figure 2: Example of results from GIS analysis

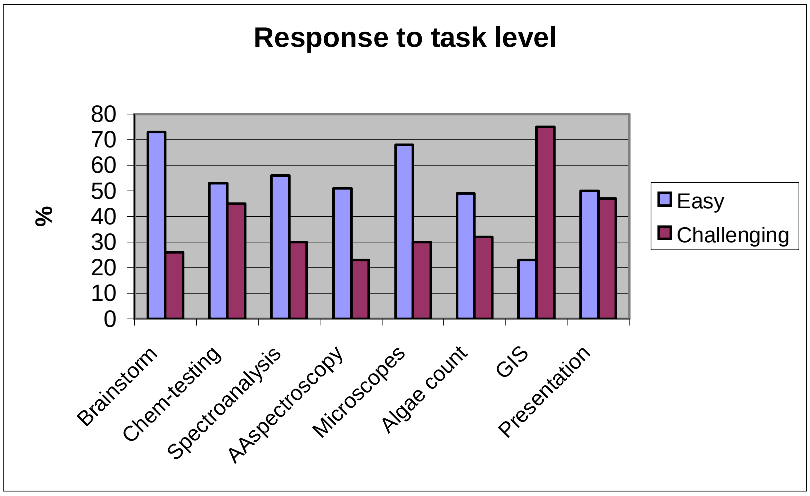
A brief overview (15 minutes) of GIS and its capabilities and the data sets was given to the students. A detailed handout was provided to the students to enable them to work their way progressively through the problem with minimal intervention. A number of tutors were on hand to assist the students to answer questions and to assist in the use of the software when problems arose.

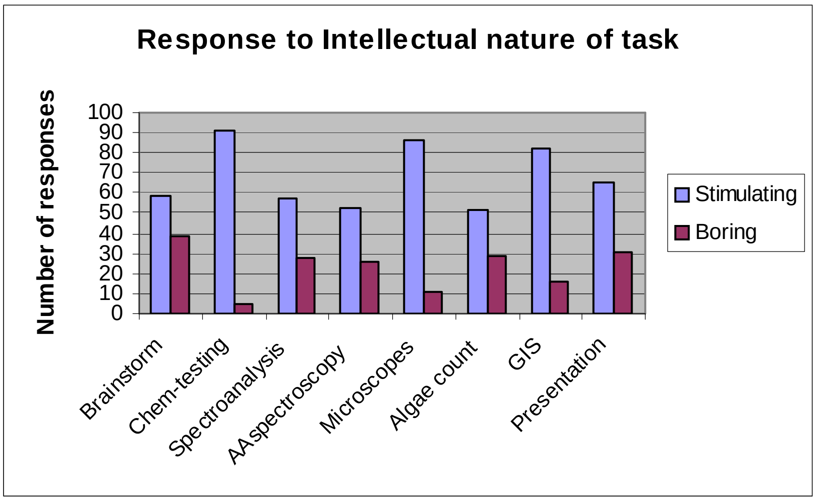
During their analysis the students utilised a range of GIS analysis tools to arrive at a solution in the time frame available. These tools included:

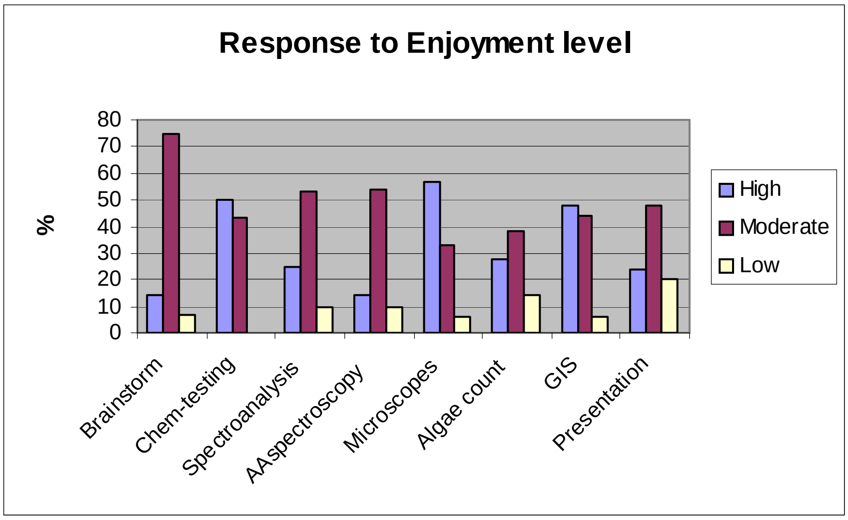
- overlay analysis to exclude areas that were free of contamination
- buffering of streams, and
- measurement of distance

Results of Students' Responses to the PBL approach

Response	Easy	Challenging	Total	High	Moderate	Low	Stimulating	Boring
Brainstorm	73	26	99	14	75	7	58	39
Chem-testing	53	45	98	50	43	0	91	5
Spectroanalysis	56	30	86	25	53	10	57	28
AAspectroscopy	51	23	74	14	54	10	52	26
Microscopes	68	30	98	57	33	6	86	11
Algae count	49	32	81	28	38	14	51	29
GIS	23	75	98	48	44	6	82	16
Presentation	50	47	97	24	48	20	65	31


Response to task level
%
80
70
60
50
40
30
20
10
0
Brainstorm
Chem-testing
Spectroanalysis
AAspectroscopy
Microscopes
Algae count
GIS
Presentation
Easy
Challenging


Response to Intellectual nature of task
Number of responses
100
90
80
70
60
50
40
30
20
10
0
Brainstorm
Chem-testing
Spectroanalysis
AAspectroscopy
Microscopes
Algae count
GIS
Presentation
Stimulating
Boring


Response to Enjoyment level
%
80
70
60
50
40
30
20
10
0
Brainstorm
Chem-testing
Spectroanalysis
AAspectroscopy
Microscopes
Algae count
GIS
Presentation
High
Moderate
Low

Discussion

Pros and Cons of PBL

The zealots of the approach suggest that it provides students with motivation, greater responsibility for their own progress, improves their research and deduction skills and encourages them to think laterally. On the other hand the traditionalists argue that this approach is content poor, time consuming and often difficult to evaluate the quality of the student outcomes. Some fear that this approach will leave students at a disadvantage in large-scale achievement tests, which have become increasingly important indicators of science learning (Schneider *et al.*, 2002).

The research on this topic is still in its early stages, but already results indicate that the students produced by this method are comparable in their knowledge base to those taught by lecture based learning (LBL). Michel *et al.*, (2002) identified in his study of two groups of university students completing the same pharmacology course at the same university showed no significant difference in their level of knowledge. The study by Schneider *et al.*,(2002) supports these findings. The study compared the high school students taught by project-based science (PBS) to see if they would perform as well as non-PBS students in the national achievement tests. They found that the performance was relatively homogeneous across grade, gender and teacher. It was found that the PBS students performed significantly higher than students nationwide on many items of the National Assessment of Educational Progress (NAEP) tests. In addition, Schneider *et al.*, (2002) found that the PBS students scored higher in questions when the length of the response increased. It indicated that the problem solving approach had encouraged students to extend their thinking and to express their ideas in a variety of ways.

Educators are constantly being told that students cannot think and are unable to solve real life problems. Abbott and Warfield (1999), found that teachers generally agree with this premise. They found that many high school teachers and students lacked a clear understanding of what problem solving involved. Although Abbott and Warfield (1999), found that teachers agreed that problem solving was a useful skill, their understanding of the problem solving process, and, in particular, assessment was vague. Moore (1997) found in her study of primary school problem solving, that while teachers were almost unanimous in the value they assigned to information skills in promoting life-long learning, they were a long way from operationalising this in terms of classroom practice.

As in the tertiary system, high school teachers face hurdles in the introduction of new concepts and teaching methods into a relatively conservative and traditional teaching framework. The implementation of PBL methods will vary according to the individual, the curriculum content, the student's ability and the teaching environment.

It could be generalised that early level students in high school will require clear and well structured problems to gain the students' confidence so as not to be overwhelmed by the lack of direction. Ronny, McCurdy and Ballinger (1984, p.80) suggested that field dependent (or discipline dependent) students might benefit from carefully structured instruction and clearly defined objectives. In contrast, it may be expected that problem solving at tertiary level would involve more complex and open-ended problems that require more experienced problem solving skills, extended research for solutions, but nonetheless a degree of guidance to effect a solution.

Problem solving is a skill that can be taught, just as scientific methods and testing procedures may be taught. Just as athletes must practice to excel, one cannot succeed at problem solving without practice (Abbott and Warfield, 1999)

Gender, Attitude and Achievement Differences – will computers help to close the gap?

Research on performance of science achievement and attitudes indicate that they begin to illustrate differences by gender, favouring boys, during the middle school years. These differences come at a time when most students are about to enter a period of schooling in which they are allowed to make course choices that can be critical to their future education (Mattern and Schau, 2002). This research also indicates that appearance of this middle school gender gap in science achievement coincides with a decline in girl's science self-concept and in other components of their attitudes towards science. Oliver (1990) found that the decline in both the attitude towards science and science motivation for boys and girls from grade 6 to 10. They found that boys generally showed a more positive attitude and achievement in science although girls indicated a higher science motivation than boys.

However, not all research on the performance of boy and girls in science have reached the same conclusions. Kumar and Helgeson's (2000) study found mixed results in their study on gender-based differences in utilising computers in chemistry. The authors found that although some obvious differences could be identified, the use of computers as problem solving tools as well as the ability for computers to give immediate responses may have contributed to the narrowing of the gender gap.

More effort required

Students who have participated in problem based learning often report that it is more difficult than the traditional learning methods. In particular, many students believe do not appreciate the addition effort required to research the problem and identify the additional resources required to address the problem (Cruickshank and Olander, 2002). Others identify frustration due to the lack of detailed instructions provided by the instructor or the common situation that there may be more than one solution.

Current School System

Currently, in most schools, a set curriculum demands that the teacher selects the appropriate knowledge, processes, skills, and values to be learned, and adapts it to the learning abilities of the class. This often involves the teacher giving the knowledge, in the form of 'chalk and talk' or worse still, in the form that students detest the most – copying notes off the board, or from a book. Sometimes, a variety of structured learning activities are carried out by the students during lab time, but again in a rather controlled learning environment. Few teachers have ever thought of giving their students the freedom of thinking for themselves, let alone the teaching of thinking skills in its many forms. From a teacher's point of view, I can understand why teaching and learning has been so structured, because of many constraints other than those described or implied above.

From a classroom teacher's perspective, I have had some freedom in designing my own science courses for my classes. But ultimately, I had to prepare them for 'the exam'.

Until such time as when the whole science teaching and learning undergoes a paradigm shift through micro- systemic reforms at each local level, teachers who desire more out of their teaching and their students' learning will continue to introduce new ideas into their own classrooms while that 'exam' still reigns in our school system.

Conclusion

Although problem solving is identified as a major outcome in science learning, teachers are not trained to teach problem solving (Blosser, 1988). From my own experience as a science teacher, I suspect that many teachers do know what is involved to teach problem solving, but that most have focused on the types of problem solving that would help their students to gain good marks in their Year 12 exams? Teachers are bound in many ways by a system of assessment that still serves the universities.

I believe that students have a need for mental challenge, at various levels of their learning spectrum. However, most science teachers have a tendency to under extend their students' thinking capacity. In today's knowledge society, science teaching must move beyond focussing on understanding and application of science concepts. These basic higher order thinking skills must not only be taught but utilised for real-life problem-solving. Relevance and context are two key factors that will help to engage our students' interest in science. It is true that not all students are going to be in a science career, but all students will solve real-life problems during their lifetime. As science teachers, we know how powerful the scientific method is for solving problems. But problem solving in school currently takes the form of textbook exercises involving the use of algorithms, although these play an important part in knowledge and concept application. The scientific method of thinking is to be enriched by something vital in this post-industrial era - knowledge management and technology. We need to move towards a big-picture mindset in science teaching and learning.

References

Abbott, L. & Warfield, A. (1999) *Improving the problem solving skills of math and science students at the high school level,* Masters Project, St. Xavier University, Chicago, Illinois.

Cruickshank, B. J. & Olander, J. (2002) Can problem-based instruction stimulate higher order thinking?, *Journal of College Science Teaching,* vol. 31, no. 6, pp. 374-377.

Educational Development Unit of London Guildhall University (2002) *Problem-based learning,* Available: <http://www.lgu.ac.uk/deliberations/pbl/> (15 May, 2002).

Kumar, D. D. & Helgeson, S. L. (2000) Effect of gender on computer-based chemistry problem solving: Early findings, *Electronic Journal of Science Education,* vol. 4, no. 4.

Mattern, N. & Schau, C. (2002) Gender differences in science attitude-achievement relationships over time among white middle-school students, *Journal of Research in Science Teaching,* vol. 39, no. 4, pp. 324-340.

Michel, M. C., Bischoff, A. & Jakobs, K. H. (2002) Comparison of problem- and lecture-based pharmacology teaching, *Trends in Pharmacological Sciences*, vol. 23, no. 4, pp. 168-170.

Moore, P. (1997) Teaching information problem solving in primary schools: An information literacy survey, *Proceedings of 63rd International Federation of Library Associations General Conference,* 31 August -5 September 1997.

Schneider, R. M., Krajcik, J., Marx, R. W. & Soloway, E. (2002) Performance of students in project-based science classrooms on a national measure of science achievement, *Journal of Research in Science Teaching,* vol. 39, no. 5, pp. 410-422.

Struijker Boudier, H. A. & Smits, J. F. (2002) Problem-based learning the Maastricht experience, *Trends in Pharmacological Sciences,* vol. 23, no. 4, p. 164.

United States Geological Survey (2002) *USGS website on GIS*, Available: <http://www.usgs.gov/research/gis/title.html> (16 May, 2002).